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Method and apparatus for measuring the apparent frequency shift of ultrasound pulses in tissue.

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10cd A zero crossing detection circuit for estimating the ultrasonic attenuation in a region of interest in the body from an A-line signal which is representative of pulses of ultrasound energy reflected from said region. The ultrasound attenuation is estimated from the center frequency fZ of the returned energy which is calculated from the formula: as measured at various depths in the body.

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(54) **Method and apparatus for measuring the apparent frequency shift of ultrasound pulses in tissue.**

(57) A zero crossing detection circuit and method for estimating the ultrasonic attenuation in a region of interest (210) in the body (200) from an A-line signal A(t) which is representative of pulses of ultrasound energy reflected from said region. The A-line signal A(t) is converted into a square pulse train signal $V_u(t)$ which has a value of zero when the instantaneous voltage of the A-line signal is at or below zero and which has a value of V_{ref} whenever the instantaneous voltage of the A-line signal is greater than zero. The ultrasound attenuation is estimated from the center frequency f_Z of the return energy which is calculated from the formula:

$$f_z = \frac{n.V_{ref}}{2\int V_u(t)dt}$$

as measured at various depths in the body, n being the number of pulses in the pulse train signal.

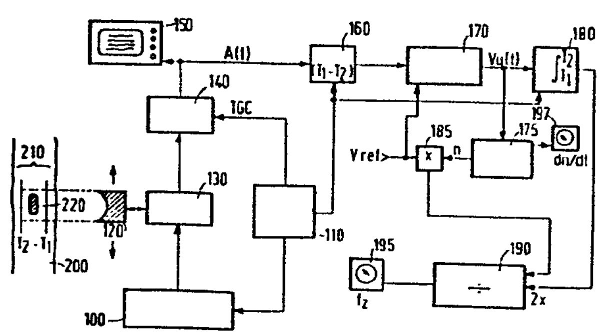

FIG.1

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"Method and apparatus for measuring the apparent frequency shift of ultrasound pulses in tissue"

The invention relates to a method for determining the apparent frequency of ultrasound echoes which are returned from a region-of-interest within a body, comprising the steps of directing pulses of ultrasound energy into the region-of-interest of the body and for producing an A-line signal which represents the intensity of a series of echoes reflected in the region-of-interest. The invention also relates to an apparatus for calculating the apparent frequency of ultrasound pulses-echoes in tissue in a region-of-interest in a body comprising means for directing pulses of ultrasound energy into the body and for detecting echoes from the region-of-interest of the energy in the form of an A-line signal. Energy from the pulses is reflected from impedance discontinuities, which may occur at organ boundaries or at lesions within otherwise healthy, homogeneous tissue.

The amplitude of echoes which have reflected from the body may be plotted as a function of time to produce an A-line which represents the magnitude of impedance discontinuities at various distances along the ultrasound propagation path. If the propagation path is scanned across the body, the resultant A-lines may be combined on a two-dimensional display to produce an image of the interior of the body.

Ultrasound energy is attenuated as it passes through tissue. The magnitude of the attenuation in a local region of the body may be used to characterize the type and condition of tissue in that region and may be used, for example, to differentiate between various organs or between healthy and diseased tissue.

The ultrasonic attenuation of animal tissue is known to vary as a function of frequency and, as a result, the center frequency of a wideband ultrasound pulse will appear to shift as a function of both the tissue type and the length of the propagation path through the tissue. The apparent shift in the center frequency of ultrasound pulses reflected from a region of tissue may be used to estimate the attenuation of that tissue in a manner

which is described in Ultrasonic Attentuation Tomography of Soft Tissues, Dines and Kak, Ultrasonic Imaging Vol. 1, No. 1, pages 16-33, 1979.

A method and an apparatus for estimating the attenuation of tissue by counting zero crossings of the signal in an A-line are described, for example, in US-A 4,441,368. This method is, however, sensitive to drop-outs or reductions in the amplitude of the A-line signal which may, for example, occur when ultrasound propagates through a cyst and the resultant measurements of attenuation may be inaccurate or confusing when made in the vicinity of cysts.

It is an object of the invention to provide an improved apparatus and method for measuring the apparent frequency shift of ultrasound echoes.

The method according to the invention is characterized in that it further comprises the steps of:

converting said A-line signal into a square pulse train signal which has a value of zero whenever the instantaneous voltage of the A-line signal is at or below zero and which has a value of V_{ref} whenever the instantaneous voltage of the A-line signal is greater than zero;

calculating the apparent center frequency f_Z of the echoes from the formula:

$$f_Z = \frac{n.V_{ref}}{2 \int V_u(t)dt}$$

wherein $V_u(t)$ represents the square wave pulse train signal and n is the number of pulses in said pulse train signal which are returned from the region of interest.

A first embodiment of the apparatus according to the invention is characterized in that it further comprises:

a gate circuit adapted to gate the A-line signal and to pass only portions of the A-line signal which represent echoes which originate in the region-of-interest;

a limiter circuit for converting the output of the gate circuit into a train of pulses which have a value V_{ref} whenever the A-line signal has a value above zero and which have a zero

value whenever the value of the A-line signal is at or below zero;

an integrator circuit for integrating the train of pulses;

a pulse counter for counting the number of pulses in the train of pulses;

a multiplier circuit for multiplying the value V_{ref} by the output of the pulse counter;

a divider circuit for dividing the output of the multiplier circuit by the output of the integrator circuit; and

a display for displaying the resultant quotient as the value of the apparent center frequency of the echoes.

A second embodiment of the apparatus according to the invention is characterized in that it further comprises:

a gate circuit adapted to gate the A-line signal and to pass only portions of the A-line signal which represent echoes which originate in the region-of-interest;

a limiter circuit for converting the output of the gate circuit into a train of pulses which have a value V_{ref} whenever the A-line signal has a value above zero and which have a zero value whenever the value of the A-line signal is at or below zero;

a first integrator circuit for integrating the train of pulses;

a pulse counter for counting the number of pulses in the train of pulses;

a second integrator circuit for integrating the reference signal value V_{ref};

a first multiplier circuit for multiplying the integrated value of the reference signal by the value of the output of the pulse counter;

a timer for measuring the length of the portion of the A-line signal which represent echoes which originate in the region-of-interest;

a second multiplier circuit for multiplying the output of the first integrator circuit by the length of the portion of the A-line signal;

a divider circuit for dividing the output of the first multiplier circuit by the output of the second multiplier circuit; and

a display for displaying the resultant quotient as the value of the apparent center frequency of echoes originating in the region-of-interest.

The method and apparatus of the invention can be best understood by reference to the drawings in which:

Fig. 1 is a schematic drawing of a first embodiment of apparatus implementing the invention;

Fig. 2 represents a typical A-line signal;

Fig. 3 is an enlarged drawing of the region indicated by the circle in Fig. 1;

Fig. 4 illustrates a signal produced by hard limiting positive regions of an A-line signal and subsequently integrating the limited pulse train; and

Fig. 5 is an alternate circuit which compensates for drift in the reference voltage signal.

<u>A preferred embodiment.</u>

Referring to Fig. 1, a conventional medical ultrasound pulse transmitter 100 operates, in response to signals from master timing circuit 110, to drive an ultrasound transducer 120 through a TR switch 130 and to thus direct a periodic series of ultrasound pulses from the transducer 120 into a body 200. The ultrasound energy propagates through tissue in the body 200 where it is attenuated and partially reflected from impedance discontinuities. A portion of the reflected energy is returned, as echoes, to the transducer 120 where it is converted into electrical signals and directed through the TR switch 130 to an ultrasound receiver 140. The time between transmission of an ultrasound pulse and the detection of a specific echo by the transducer 120 is a direct measure of the distance between the transducer and the feature in the body which produced that echo. Thus, any echoes which occur in the interval between times T_1 and T_2 after the transmission of a pulse may be attributed to impedance discontinuities in a region-of-interest 210 within the body.

The receiver 140 amplifies the echo signals in accordance with a gain function which is controlled by a time gain compensation (TGC) signal generated by the master timing circuits 110 to compensate for the greater attenuation which is experienced by

pulses which travel longer distances through tissue. The output of the receiver is an A-line signal A(t) which can be displayed on a CRT 150 using well known techniques, to produce an image of the interior of the body. Fig. 2 represents a typical portion of an A-line signal A(t) thus generated.

The A-line signal A(t) is applied to a gate 160 which is controlled by a pair of timing pulses T_1 and T_2 so that it passes only that portion of the A-line signal representative of echoes generated within the region-of-interest 210. Fig. 3 is an enlarged view of a portion of the A-line signal A(t) within the gate interval which is designated by the circle 300 in Fig. 2. The interval Δ_t between the positive going and negative going zero crossings of the A-line signal A(t) is a measure of the instantaneous center frequency of the returned echo signal and, in a known manner, may be used to estimate the attenuation within the region-of-interest.

The output of the gate 160, which is the portion of the A-line signal originating within the region-of-interest 210, is applied to the input of a hard limiting circuit 170 which clamps positive regions of the A-line signal A(t) to a reference level V_{ref} and negative regions of the A-line signal to ground level. The output of the limiter is indicated by the dashed line in Fig. 3 and by the representative pulse train $V_u(t)$ in upper plot of Fig. 4. The region 320 in Fig. 4 represents a drop-out in the A-line signal A(t) of the type which may result, for example, from ultrasound propagation through a cyst (indicated as region 220 in Fig. 1).

The output of the limiter 170 is integrated, in an integrator circuit 180. The output of the integrator 180 is indicated as the lower plot of Fig. 4.

The output of the limiter 170 is also applied to a pulse counter 175. The output of the pulse counter is multiplied by the value of V_{ref} in a multiplier 185. The output of the multiplier 185 is divided by the output of the integrator 180 in a divider circuit 190. The quotient output of the divider 190 is proportional to the apparent center frequency f_z of the energy returned from the region of interest and is indicated on a display 195. The pulse rate dn/dt at the output of the pulse counter is likewise indicated on a display 197.

The circuit of Fig. 1 calculates the center frequency

of the returned energy in the region of interest f_Z from the formula:

$$f_Z = \frac{n.V_{ref}}{2\int V_u(t)dt}$$

The output of the divider 190, f_Z, is not affected by signal drop-outs in the A-line signal A(t). Reference to the indicator 197, which indicates the number of pulses in the signal from the region-of-interest, provides an indication of when drop-outs occur.

The value of f_Z should converge. Unstable readouts of f_Z from the divider 190 will indicate, by visual inspection, that an inhomogeneous region is being scanned. The circuit provides a real time indication of the value of the center frequency while a region is being scanned and thus favors interpretation and understanding of the technique.

The circuit of Fig. 5 compensates for drift in the reference voltage V_{ref} by calculating the center frequency of the returned energy from the formula:

$$f_Z = \frac{n}{2t} \frac{\int V_{ref}(t)dt}{\int V_u(t)dt}$$

Fig. 5 shows an alternative circuit for calculating f_Z from the A-line signal A(t). The gate 160, limiter 170, first integrator 180, pulse counter 175, divider 190 and displays 195 and 197 serve the same purpose as has been described with respect to Fig. 1. A timer 250 is connected to the input of gate 160 and measures the width of the gate interval T_1-T_2. The output of the timer 250 is indicated on a display 260. The value of V_{ref} which serves as a reference for the limiter circuit 170 is integrated over T_2-T_1 in a second integrator 270 and then applied to the input of the first multiplier 185. The output of the first integrator 180 is multiplied by the output of the timer 250 in a second multiplier 280 and then applied to the input of the divider 190.

If desired, the sensitivity of the circuit to noise may

be reduced by inserting a threshold circuit 165 between the gate 160 and the limiter 170.

The accuracy of the apparent frequency measurement depends on the statistics of the A-line signal A(t). If desired, the statistics may be improved by accumulating the integrals and pulse count from a plurality of A-lines through the region-of-interest in first integrator 180 and pulse counter 175.

CLAIMS

1. Method for determining the apparent frequency of ultrasound pulse-echoes in a region of interest of a body comprising the steps of directing pulses of ultrasound energy into the region-of-interest of the body and producing an A-line signal which represents the intensity of a series of echoes reflected in the region-of-interest, characterized in that it further comprises the steps of:

converting said A-line signal into a square pulse train signal which has a value of zero whenever the instantaneous voltage of the A-line signal is at or below zero and which has a value of V_{ref} whenever the instantaneous voltage of the A-line signal is greater than zero;

calculating the apparent center frequency f_Z of the echoes from the formula:

$$f_Z = \frac{n.V_{ref}}{2\int V_u(t)dt}$$

wherein $V_u(t)$ represents the square wave pulse train signal and n is the number of pulses in said pulse train signal which are returned from the region of interest.

2. Apparatus for calculating the apparent frequency of ultrasound pulses-echoes in tissue in a region-of-interest in a body comprising means for directing pulses of ultrasound energy into the body and for detecting echoes from the region-of-interest of the energy in the form of an A-line signal, characterized in that it further comprises:

a gate circuit adapted to gate the A-line signal and to pass only portions of the A-line signal which represent echoes which originate in the region-of-interest;

a limiter circuit for converting the output of the gate circuit into a train of pulses which have a value V_{ref} whenever the A-line signal has a value above zero and which have a zero

value whenever the value of the A-line signal is at or below zero;

an integrator circuit for integrating the train of pulses;

a pulse counter for counting the number of pulses in the train of pulses;

a multiplier circuit for multiplying the value V_{ref} by the output of the pulse counter;

a divider circuit for dividing the output of the multiplier circuit by the output of the integrator circuit; and

a display for displaying the resultant quotient as the value of the apparent center frequency of the echoes.

3. Apparatus for calculating the apparent frequency of ultrasound pulse-echoes and tissue in a region-of-interest in a body comprising means for directing pulses of ultrasound energy into the body and for detecting echoes from the region-of-interest of the energy in the form of an A-line signal, characterized in that it further comprises:

a gate circuit adapted to gate the A-line signal and to pass only portions of the A-line signal which represent echoes which originate in the region-of-interest;

a limiter circuit for converting the output of the gate circuit into a train of pulses which have a value V_{ref} whenever the A-line signal has a value above zero and which have a zero value whenever the value of the A-line signal is at or below zero;

a first integrator circuit for integrating the train of pulses;

a pulse counter for counting the number of pulses in the train of pulses;

a second integrator circuit for integrating the reference signal value V_{ref};

a first multiplier circuit for multiplying the integrated value of the reference signal by the value of the output of the pulse counter;

a timer for measuring the length of the portion of the A-line signal which represent echoes which originate in the region-of-interest;

a second multiplier circuit for multiplying the output of the first integrator circuit by the length of the portion of

the A-line signal;

a divider circuit for dividing the output of the first multiplier circuits by the output of the second multiplier circuit; and

a display for displaying the resultant quotient as the value of the apparent center frequency of echoes originating in the region-of-interest.

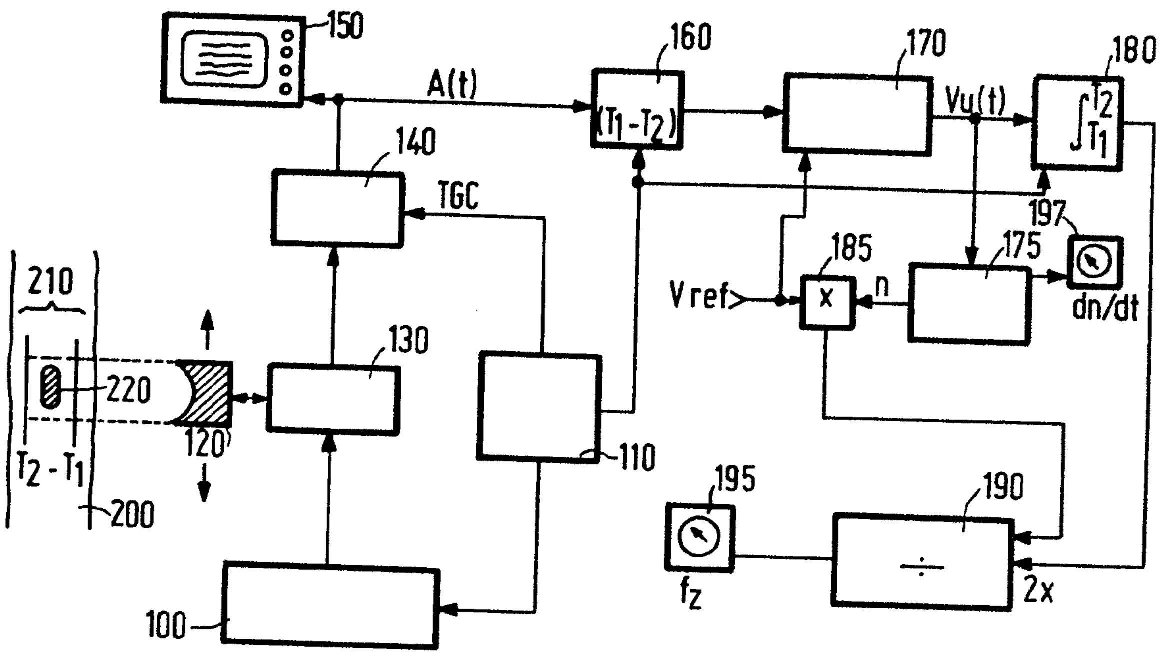
150
A(t)
160
(T1-T2)
170
Vu(t)
180
140
TGC
197
185
175
Vref
n
dn/dt
210
130
220
120
T2 - T1
110
200
195
190
fz
2x
100

FIG. 1

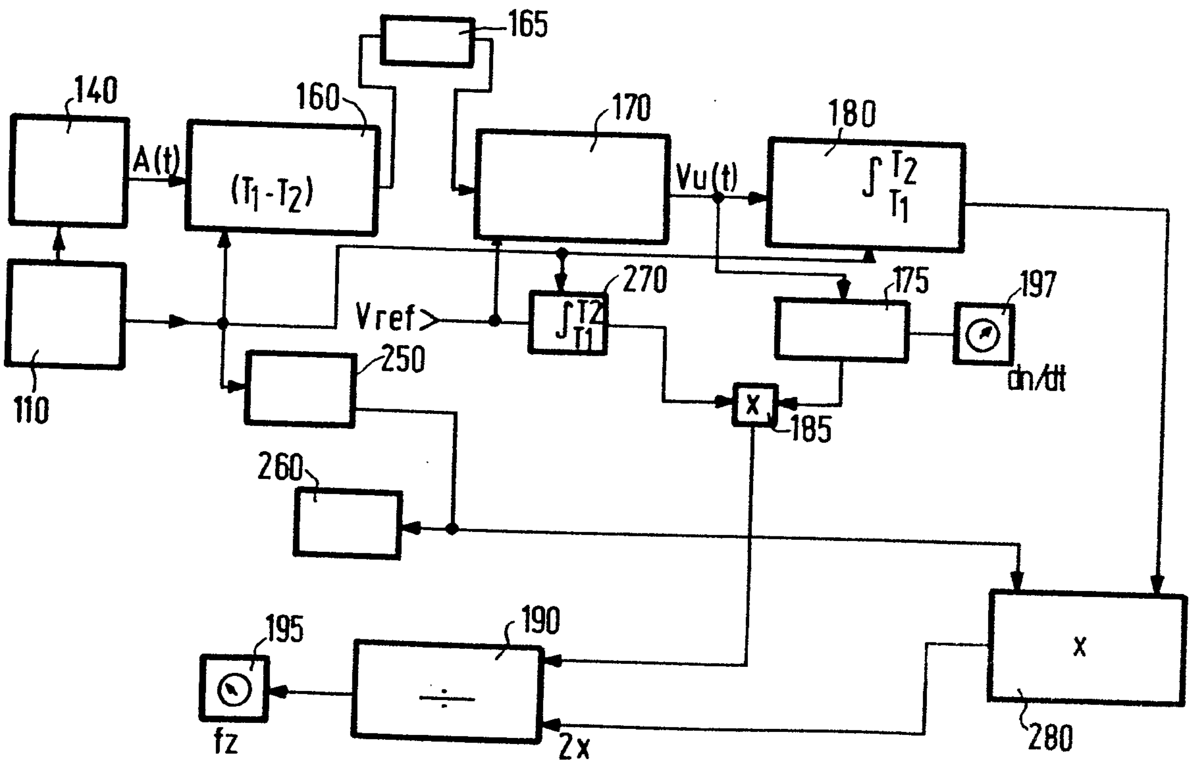
165
140
160
170
180
A(t)
(T1-T2)
Vu(t)
270
175
197
Vref
110
250
185
dn/dt
260
195
190
280
fz
2x

FIG. 5

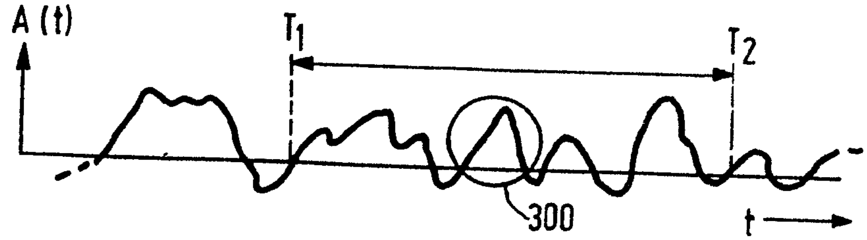

FIG. 2

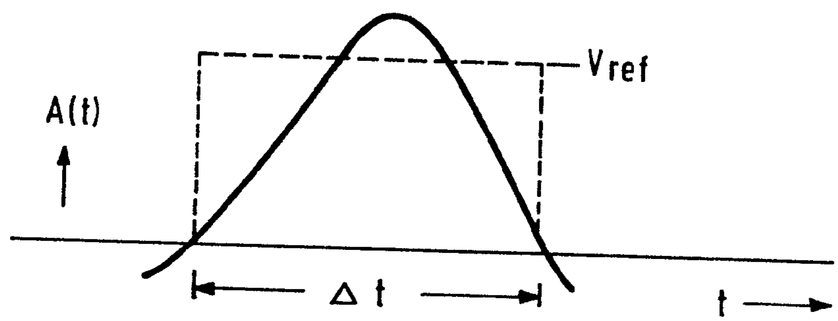

FIG. 3

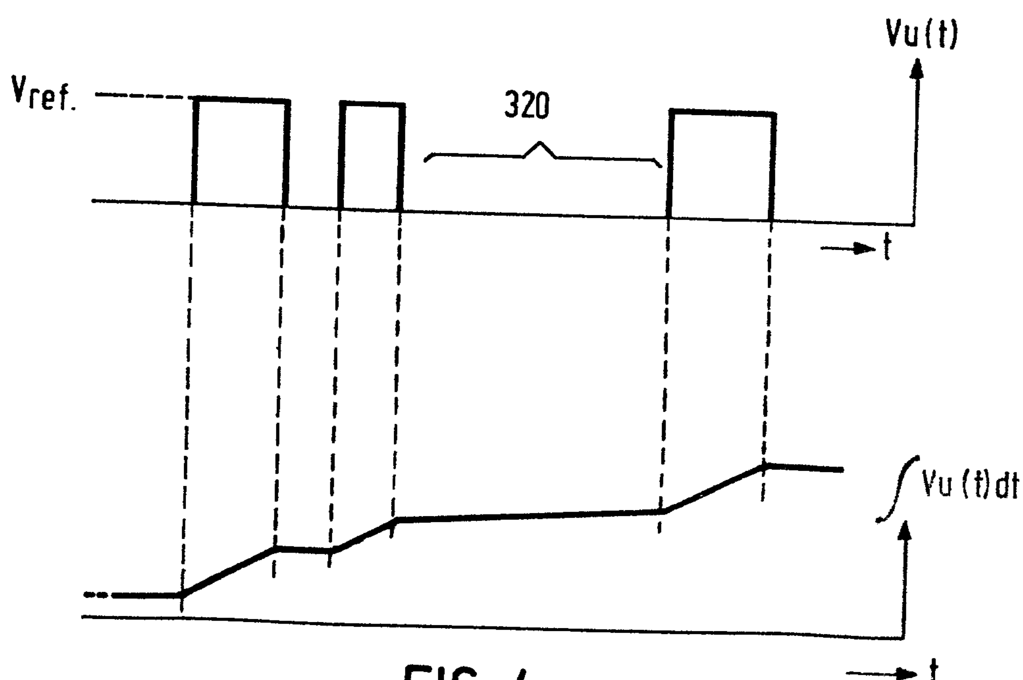

FIG. 4

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EUROPEAN SEARCH REPORT

0181668

Application number

EP 85 20 1748

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	IEEE TRANSACTIONS ON ACOUSTICS, SPEECH AND SIGNAL PROCESSING, vol.ASSP-32, no. 1, February 1984, pages 1-6, IEEE, New York, US; R. KUC: "Estimating acoustic attenuation from reflected ultrasound signals: comparison of spectral-shift and spectral-difference approaches" * Page 1, abstract; page 4, sub-section 3, "Zero-crossing method" * ---	1	G 01 S 7/52 G 01 S 15/02 G 01 S 15/89 // A 61 B 8/00
A	EP-A-0 092 191 (GENERAL ELECTRIC CO.) * Abstract; page 1, lines 1-5; page 4, first line - page 8, line 5; page 11, line 15 - page 18, line 7 * ---	1,2	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	US-A-3 803 487 (ITEN) * Abstract; column 2, line 46 - column 3, line 20; column 3, line 37 - column 5, line 35; column 5, line 60 - column 7, line 8 * ---	1,2	G 01 S G 01 R G 01 H
A	US-A-3 280 937 (FABER,Jr. et al.) * Column 2, line 57 - column 3, line 2; column 4, line 12 - column 5, line 16 * --- -/-	1,2	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	03-02-1986	OLDROYD D.L.

CATEGORY OF CITED DOCUMENTS

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	1983 IEEE ULTRASONICS SYMPOSIUM PROCEEDINGS, vol. 2, 1983, pages 835-840, IEEE, New York, US; J.L. BERNATETS et al.: "Estimation of frequency dependent attenuation in biological tissue by a time-frequency representation of the echographic A-lines" ---		
A	ULTRASONIC IMAGING, vol. 5, no. 2, April 1983, pages 95-116, Academic Press, New York, US; S.W. FLAX et al.: "Spectral characterization and attenuation measurements in ultrasound" ---		
A	IEEE TRANSACTIONS ON SONICS AND ULTRASONICS, vol. SU-31, no. 4, July 1984, pages 352-361, IEEE, New York, US; S. LEEMAN et al.: "Perspectives on attenuation estimation from pulse-echo signals" -----		TECHNICAL FIELDS SEARCHED (Int. Cl.4)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	03-02-1986	OLDROYD D.L.

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